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Takashi KANO and Hiroki OHBO

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APPLICATION ELEMENTS FOR:
SEMICONDUCTOR LASER DEVICE

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PAGE 2 OF 3

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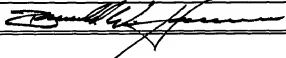
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TITLE OF THE INVENTION

Semiconductor Laser Device

BACKGROUND OF THE INVENTION

5 Field of the Invention

The present invention relates to a semiconductor laser device made of a group III-V nitride based semiconductor (hereinafter referred to as a nitride based semiconductor) such as BN (boron nitride), GaN (gallium nitride), AlN (aluminum nitride), InN (indium nitride) or TiN (thallium nitride) or mixed crystals thereof.

Description of the Prior Art

In recent years, GaN based semiconductor light emitting devices are increasingly put into practice as semiconductor laser devices emitting blue or violet light. Such semiconductor laser devices are generally employed as the light sources for optical disk systems writing and reading information in and from an optical disk among optical memories optically writing or reading information. In particular, GaN based semiconductor laser devices are expected as the light sources for high-density optical disk systems such as advanced digital video disks.

Fig. 12 is a typical sectional view of a conventional GaN based semiconductor laser device. Referring to Fig. 12,

an undoped GaN low-temperature buffer layer 52, an undoped GaN layer 53, an n-GaN layer 54, an n-anti-cracking layer 55, an n-AlGaIn cladding layer 56, an n-GaN light guide layer 57 and an InGaIn multiple quantum well (MQW) active layer 58 are
5 successively provided on a sapphire substrate 51.

Further, a p-AlGaIn carrier blocking layer 59, a p-GaN light guide layer 60 and a p-AlGaIn first cladding layer 61 are successively provided on the active layer 58. An n-GaN current blocking layer 62 having a striped opening 63 is formed on the
10 p-AlGaIn first cladding layer 61. A p-AlGaIn second cladding layer 64 and a p-GaN contact layer 65 are successively provided on the p-AlGaIn first cladding layer 61 located in the striped opening 63 and the n-GaN current blocking layer 62.

Partial regions of the layers from the p-GaN contact layer
15 65 to the n-GaN layer 54 are removed by etching, to expose the n-GaN layer 54. A p type electrode 66 is formed on the upper surface of the p-GaN contact layer 65, and an n type electrode 67 is formed on the exposed upper surface of the n-GaN layer 54.

20 In the semiconductor laser device shown in Fig. 12, electrons (negative carriers) supplied from the n type electrode 67 are injected into the active layer 58 through the n-GaN layer 54, the n-anti-cracking layer 55, the n-AlGaIn cladding layer 56 and the n-GaN light guide layer 57. Holes
25 (positive carriers) supplied from the p type electrode 66 are

injected into the active layer 58 through the p-GaN contact layer 65, the p-AlGaIn second cladding layer 64, the p-AlGaIn first cladding layer 61, the p-GaN light guide layer 60 and the p-AlGaIn carrier blocking layer 59.

5 The n-GaN current blocking layer 62 having the striped opening 63 is provided in order to reduce operating current and limit an emission spot position by limiting the flow of current in a striped manner. The n-GaN current blocking layer 62 limits the current flowing into the active layer 58
10 substantially to the region located under the striped opening 63.

In the aforementioned conventional semiconductor laser device, however, the n-GaN current blocking layer 62, having a larger refractive index as compared with the p-AlGaIn first
15 cladding layer 61 and the p-AlGaIn second cladding layer 64, has no effect of light confinement.

In order to bring the semiconductor laser device into a real refractive index guided structure for attaining the effect of light confinement, the n-current blocking layer must
20 be made of n-AlGaIn, for example, in a larger Al composition ratio than the p-AlGaIn first cladding layer 61 and the p-AlGaIn second cladding layer 64 so that the refractive index thereof is smaller than those of the p-AlGaIn first cladding layer 61 and the p-AlGaIn second cladding layer 64. Thus, the effective
25 refractive index in the region of the active layer 58 located

under the n-current blocking layer is smaller than that of the region of the active layer 58 located under the p-AlGa_N second cladding layer 64 in the striped opening 63. Consequently, light is confined in the central portion of the active layer 58. In this case, however, the p-AlGa_N first cladding layer 61 and the p-AlGa_N second cladding layer 64, which are also made of n-AlGa_N, and the n-AlGa_N current blocking layer provide a large AlGa_N film thickness in total. Such a film having a large Al composition is readily cracked if the thickness thereof is too large.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a semiconductor laser device having a current blocking layer, which is excellent in thermal stability and prevented from cracking.

Another object of the present invention is to provide a semiconductor laser device having a current blocking layer, which is excellent in thermal stability, prevented from cracking and improved in effect of light confinement.

A semiconductor laser device according to an aspect of the present invention comprises a first nitride based semiconductor layer including an active layer and containing at least one of boron, aluminum, gallium, indium and thallium, a current blocking layer, formed on the first nitride based

semiconductor layer, having a striped opening, and a second nitride based semiconductor layer, formed on the first nitride based semiconductor layer in the striped opening, containing at least one of boron, aluminum, gallium, indium and thallium, and the current blocking layer includes a multilayer structure of at least one first layer of a nitride based semiconductor containing at least one of aluminum and boron and at least one second layer of a nitride based semiconductor containing indium and having a smaller band gap than the first layer.

In this semiconductor laser device, the first layer of the current blocking layer contains at least one of boron and aluminum, whereby the band gap of the first layer can be increased for reducing the refractive index of the first layer. Thus, in the case of a real refractive index guided structure, the difference in refractive index between the current blocking layer and the second nitride based semiconductor layer in the striped opening can be increased. Further, the first layer of the current blocking layer containing at least one of boron and aluminum is thermally stabilized. In addition, the second layer of the current blocking layer containing indium can absorb strain caused in the first layer containing boron or aluminum. Thus, cracking is suppressed.

Therefore, a semiconductor laser device having a real refractive index guided structure excellent in thermal stability, prevented from cracking and improved in effect of

light confinement is implemented. Alternatively, a semiconductor laser device having a loss guided structure excellent in thermal stability and prevented from cracking is implemented.

5 At least one first layer may have a larger aluminum composition ratio than that of at least one second layer or a larger boron composition ratio than that of at least one second layer, and at least one second layer may have a larger indium composition ratio than that of at least one first layer.

10 In this case, at least one first layer is reduced in refractive index and improved in thermal stability. Further, at least one second layer absorbs strain of at least one first layer.

 The first nitride based semiconductor layer may include
15 a first conductivity type cladding layer, the active layer and a second conductivity type first cladding layer in this order, and the second nitride based semiconductor layer may include a second conductivity type second cladding layer.

 At least one first layer may include at least two first
20 layers, and at least two first layers and at least one second layer may be alternately stacked.

 In this case, the second layer held between the first layers effectively absorbs strain caused in the first layers arranged on both sides thereof.

25 The mean refractive index of the current blocking layer

may be smaller than the refractive index of the second nitride based semiconductor layer in the striped opening. In this case, the effective refractive index in the region of the active layer located under the current blocking layer is smaller than the effective refractive index in the region of the active layer located under the striped opening, and light is concentrated to the region of the active layer located under the striped opening. Thus, a semiconductor laser device having a real refractive index guided structure is implemented.

The mean band gap of the current blocking layer may be larger than the band gap of the second conductivity type second cladding layer. In this case, the mean refractive index of the current blocking layer is smaller than the refractive index of the second conductivity type second cladding layer in the striped opening. Thus, the effective refractive index in the region of the active layer located under the current blocking layer is smaller than the effective refractive index in the region of the active layer located under the second conductivity type second cladding layer in the striped opening, and light is concentrated to the region of the active layer located under the striped opening. Consequently, a semiconductor laser device having a real refractive index guided structure is implemented.

The active layer may include at least one quantum well layer and at least two quantum barrier layers alternately

stacked, and the band gap of at least one second layer may be larger than the band gap of at least one quantum well layer. In this case, the mean band gap of the current blocking layer can be readily rendered larger than the band gap of the second conductivity type second cladding layer.

The active layer may contain indium, gallium and nitrogen, at least one first layer may contain at least one of aluminum and boron as well as gallium and nitrogen, at least one second layer may contain indium, gallium and nitrogen, and the first conductivity type cladding layer, the second conductivity type first cladding layer and the second conductivity type second cladding layer may contain aluminum, gallium and nitrogen.

At least one first layer may have a larger aluminum composition ratio than that of the second conductivity type second cladding layer or a larger boron composition ratio than that of the second conductivity type second cladding layer. Thus, the band gap of at least one first layer is larger than the band gap of the second conductivity type second cladding layer.

The active layer may include at least one quantum well layer containing indium, gallium and nitrogen and at least two quantum barrier layers containing indium, gallium and nitrogen, alternately stacked, and the indium composition ratio of at least one quantum well layer may be larger than the indium composition ratio of at least two quantum barrier layers.

The mean band gap of the current blocking layer may be substantially equal to or smaller than the band gap of the active layer.

In this case, the current blocking layer absorbs light
5 generated in the region of the active layer located under the current blocking layer, whereby light is concentrated to the region of the active layer located under the striped opening. Thus, a semiconductor laser device having a loss guided structure is implemented.

10 The active layer may include at least one quantum well layer and at least two quantum barrier layers alternately stacked, and the mean band gap of the current blocking layer may be substantially equal to or smaller than the mean band gap of the active layer. In this case, the current blocking
15 layer absorbs light generated in the active layer having a multiple quantum well structure, whereby light is concentrated to the region of the active layer located under the striped opening.

The band gap of at least one second layer may be smaller
20 than the band gap of at least one quantum well layer. In this case, the mean band gap of the current blocking layer can be readily rendered substantially equal to or smaller than the band gap of the active layer.

The active layer may contain indium, gallium and nitrogen,
25 at least one first layer may contain at least one of aluminum

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and boron as well as indium, gallium and nitrogen, at least one second layer may contain indium, gallium and nitrogen, and the first conductivity type cladding layer, the second conductivity type first cladding layer and the second conductivity type second cladding layer may contain aluminum, gallium and nitrogen.

The active layer may include at least one quantum well layer containing indium, gallium and nitrogen and at least two quantum barrier layers containing indium, gallium and nitrogen, alternately stacked, and the indium composition ratio of at least one quantum well layer may be larger than the indium composition ratio of at least two quantum barrier layers.

The first nitride based semiconductor layer may further include a first conductivity type light guide layer provided between the first conductivity type cladding layer and the active layer and a second conductivity type light guide layer provided between the active layer and the second conductivity type first cladding layer.

The semiconductor laser device may further comprise a third nitride based semiconductor layer, formed on the current blocking layer and the second nitride based semiconductor layer, containing at least one of boron, aluminum, gallium, indium and thallium.

The third nitride based semiconductor layer may include a third cladding layer of the second conductivity type and a

second conductivity type contact layer. Alternatively, the third nitride based semiconductor layer may include a second conductivity type contact layer.

The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

10 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a typical sectional view of a GaN based semiconductor laser device according to a first embodiment of the present invention;

Fig. 2 is an energy band diagram of a current blocking layer of the semiconductor laser device shown in Fig. 1 and the vicinity thereof;

Fig. 3 is an energy band diagram of a current blocking layer of a GaN based semiconductor laser device according to a second embodiment of the present invention and the vicinity thereof;

Fig. 4 is an energy band diagram of a current blocking layer of a GaN based semiconductor laser device according to a third embodiment of the present invention and the vicinity thereof;

Fig. 5 is an energy band diagram of a current blocking

layer of a GaN based semiconductor laser device according to a fourth embodiment of the present invention and the vicinity thereof;

Fig. 6 is an energy band diagram of a current blocking layer of a GaN based semiconductor laser device according to a fifth embodiment of the present invention and the vicinity thereof;

Fig. 7 is an energy band diagram of a current blocking layer of a GaN based semiconductor laser device according to a sixth embodiment of the present invention and the vicinity thereof;

Fig. 8 is a typical sectional view of the GaN based semiconductor laser device according to the sixth embodiment of the present invention;

Fig. 9 is a typical sectional view of a GaN based semiconductor laser device according to an eleventh embodiment of the present invention;

Fig. 10 is an energy band diagram of a current blocking layer of the semiconductor laser device shown in Fig. 9 and the vicinity thereof;

Fig. 11 is a typical sectional view of a GaN based semiconductor laser device according to a thirteenth embodiment of the present invention; and

Fig. 12 is a typical sectional view of a conventional GaN based semiconductor laser device.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

(1) First Embodiment

Fig. 1 is a typical sectional view of a GaN semiconductor
 5 laser device according to a first embodiment of the present
 invention. Fig. 2 is an energy band diagram of a current
 blocking layer of the semiconductor laser device shown in Fig.
 1 and the vicinity thereof.

As shown in Fig. 1, a low-temperature buffer layer 2 of
 10 undoped BALGaN having a thickness of 200 \AA , an undoped BGaN
 layer 3 of $4.5 \text{ }\mu\text{m}$ in thickness, an n-BGaN layer 4 of $4.5 \text{ }\mu\text{m}$
 in thickness and an n-anti-cracking layer 5 of $0.25 \text{ }\mu\text{m}$ in
 thickness are successively formed on a sapphire substrate 1.
 The n-anti-cracking layer 5 is formed by alternately stacking
 15 21 pairs of BALGaN layers of 60 \AA in thickness and GaN layers
 of 60 \AA in thickness.

An n-cladding layer 6 of BALGaN having a thickness of
 $0.8 \text{ }\mu\text{m}$ and an n-light guide layer 7 of BGaN having a thickness
 of $0.1 \text{ }\mu\text{m}$ are successively formed on the n-anti-cracking layer
 20 5. An $\text{n-multiple quantum well active}$ layer (hereinafter
 referred to as an MQW active layer) 8 of BInGaN is formed on
 the n-light guide layer 7. The n-MQW active layer 8 has a
 multiple quantum well structure formed by alternately stacking
 four BInGaN quantum barrier layers of each having a thickness
 25 of 50 \AA and three BInGaN quantum well layers each having a

thickness of 20 Å.

A p-carrier blocking layer 9 of AlGaIn having a thickness of 200 Å, a p-light guide layer 10 of BGaN having a thickness of 0.1 μm and a p-first cladding layer 11 of AlGaIn having a thickness of 0.2 μm are successively formed on the n-MQW active layer 8. An n-current blocking layer 12 of about 0.5 μm in thickness having a striped opening 13 is formed on the p-first cladding layer 11. A p-second cladding layer 14 of AlGaIn having a thickness of 0.7 μm is formed on the p-first cladding layer 11 located in the striped opening 13 and the n-current blocking layer 12. A p-contact layer 15 of BGaN having a thickness of 0.05 μm is formed on the p-second cladding layer 12. As shown in the energy band diagram of Fig. 2, the n-current blocking layer 12 is formed by alternately stacking five n-first current blocking layers 12a of AlGaIn each having a thickness of 0.1 μm and four n-second current blocking layers 12b of BInGaIn each having a thickness of 0.02 μm.

Partial regions of the layers from the p-contact layer 15 to the n-BGaN layer 4 are removed by etching, to expose the n-BGaN layer 4. A p type electrode 16 is formed on the contact layer 15, and an n type electrode 17 is formed on the exposed upper surface of the n-BGaN layer 4.

The semiconductor laser device shown in Fig. 1 is formed by MOCVD (metal-organic chemical vapor deposition), for example. Table 1 shows the compositions, thicknesses and

growth temperatures of the layers 2 to 12, 14 and 15 of the semiconductor laser device shown in Fig. 1.

Table 1

Name of Layer	Composition	Thickness	Growth Temperature [°C]
Low-Temperature Buffer Layer	$B_{0.1}Al_{0.4}Ga_{0.5}N$	200 Å	600
i-BGaN Layer	$B_{0.02}Ga_{0.98}N$	4.5 μm	1080
n-BGaN Layer	$B_{0.02}Ga_{0.98}N$	4.5 μm	1080
Anti-Cracking Layer	$B_{0.05}Al_{0.02}Ga_{0.93}N/GaN$	0.25 μm	1080
n-Cladding Layer	$B_{0.02}Al_{0.05}Ga_{0.93}N$	0.8 μm	1080
n-Light Guide Layer	$B_{0.02}Ga_{0.98}N$	0.1 μm	1080
Quantum Barrier Layer	$B_{0.02}In_{0.05}Ga_{0.93}N$	50 Å	800
Quantum Well Layer	$B_{0.02}In_{0.15}Ga_{0.83}N$	20 Å	800
p-Carrier Blocking Layer	$B_{0.05}Al_{0.20}Ga_{0.75}N$	200 Å	800
p-Light Guide Layer	$B_{0.02}Ga_{0.98}N$	0.1 μm	1080
p-First Cladding Layer	$B_{0.02}Al_{0.05}Ga_{0.93}N$	0.2 μm	1080
n-First Current Blocking Layer	$B_{0.02}Al_{0.07}Ga_{0.91}N$	0.1 μm	1080
n-Second Current Blocking Layer	$B_{0.02}In_{0.08}Ga_{0.90}N$	0.02 μm	800
p-Second Cladding Layer	$B_{0.02}Al_{0.05}Ga_{0.93}N$	0.7 μm	1080
p-Contact Layer	$B_{0.02}Ga_{0.98}N$	0.05 μm	1080

Si is employed as an n-type dopant, and Mg is employed

5 as a p-type dopant. As shown in Table 1, the growth temperature

of the low-temperature buffer layer 2 is 600°C, and the growth temperatures of the B_{GaN} layer 3, the n-B_{GaN} layer 4, the n-anti-cracking layer 5, the n-cladding layer 6, the n-light guide layer 7, the n-carrier blocking layer 8, the p-light guide layer 10, the p-first cladding layer 11, the n-first current blocking layers 12a and the p-contact layer 15 are 1080°C. The growth temperatures of the n-MWQ active layer 8, the p-carrier blocking layer 9 and the n-second current blocking layers 12b are 800°C.

10 TMG (trimethyl gallium), TMA (trimethyl aluminum), NH₃, and B₂H₄ are employed as raw material gases for growing the low-temperature buffer layer 2. TMG, NH₃ and B₂H₄ are employed as raw material gases for growing the B_{GaN} layer 3. TMG, NH₃ and B₂H₄ are employed as raw material gases and SiH₄ is employed
15 as a dopant gas for growing the n-B_{GaN} layer 4 and the n-light guide layer 7. TMG, TMA, NH₃ and B₂H₄ are employed as raw material gases and SiH₄ is employed as a dopant gas for growing the n-anti-cracking layer 5, the n-cladding layer 6 and the n-first current blocking layers 12a.

20 TEG (triethyl gallium), TMI (trimethyl indium), NH₃ and B₂H₄ are employed as raw material gases and SiH₄ is employed as a dopant gas for growing the n-MQW active layer 8 and the n-second current blocking layers 12b. TMG, TMA, NH₃ and B₂H₄ are employed as raw material gases and Cp₂Mg (cyclopentadienyl
25 magnesium) is employed as a dopant gas for growing the p-carrier

blocking layer 9, the p-first cladding layer 11 and the p-second cladding layer 14. TMG, NH_3 and B_2H_6 are employed as raw material gases and Cp_2Mg is employed as a dopant gas for growing the p-light guide layer 10 and the p-contact layer 15.

5 The refractive index of the n-MQW active layer 8 is higher than those of the n-cladding layer 6 and the p-cladding layer 12, and the refractive indices of the n-light guide layer 7 and the p-light guide layer 10 are lower than that of the n-MQW active layer 8 and higher than those of the n-cladding layer
10 6, the p-first cladding layer 11 and the p-second cladding layer 14.

As understood from Fig. 2, the band gap of the n-first current blocking layers 12a is larger than that of the p-first cladding layer 11 and the p-second cladding layer 14. However,
15 the band gap of the n-second current blocking layers 12b, which is smaller than that of the n-first current blocking layers 12a as well as those of the p-first cladding layer 11 and the p-second cladding layer 14, is larger than that of the quantum well layers (energy level E1 on the lower end of the conduction
20 band) forming the MQW active layer 8. The mean energy level E2 of the n-first current blocking layers 12a and the n-second current blocking layers 12b on the lower end of the conduction band is set higher than the energy level of the p-first cladding layer 11 and the p-second cladding layer 14 on the lower end
25 of the conduction band.

In the semiconductor laser device according to this embodiment, the layers from the p-first cladding layer 11 to the p-second cladding layer 14, including the n-first current blocking layers 12a, are prepared by adding at least one of B and Al to GaN, and the total thickness of these layers is about 0.9 μm . However, the n-second current blocking layers 12b of n-BInGa_N having a smaller band gap than the n-first current blocking layers 12a of n-BAlGa_N are held between the n-first current blocking layers 12a for effectively absorbing strain caused in the n-first current blocking layers 12a arranged on both sides thereof, thereby preventing cracking. In particular, the n-second current blocking layers 12b containing indium attain a large anti-cracking effect.

The mean energy level E2 of the n-current blocking layer 12 formed by the five n-first current blocking layers 12a and the four n-second current blocking layers 12b on the lower end of the conduction band is set higher than the energy level of the n-first cladding layer 11 and the p-second cladding layer 14 on the lower end of the conduction band, whereby the mean refractive index of the n-current blocking layer 12 is smaller than the refractive indices of the p-first cladding layer 11 and the p-second cladding layer 14. Thus, the effective refractive index in the region of the MQW active layer 8 located under the striped opening 13 is larger than that in the region of the MQW active layer 8 located under the n-current blocking

layer 12, and an effect of concentrating light to the region located under the striped opening 13 can be increased. Thus, a semiconductor laser device having a real refractive index guided structure is implemented.

5 The total thickness of the four n-second current blocking layers 12b having a low energy level on the lower end of the conduction band is 0.08 μm . The thickness of each n-first current blocking layer 12a having a high energy level on the lower end of the conduction band is 0.1 μm , and the total
10 thickness of the five n-first current blocking layers 12a is 0.5 μm . Thus, the mean energy level E2 of the current blocking layer 12 on the lower end of the conduction band can be controlled higher than the energy level of the p-first cladding layer 11 and the p-second cladding layer 14 on the lower end
15 of the conduction band by setting the thickness of the n-first current blocking layers 12a larger than that of the n-second current blocking layers 12b.

(2) Second Embodiment

Fig. 3 is an energy band diagram of a current blocking
20 layer 12A of a GaN based semiconductor laser device according to a second embodiment of the present invention and the vicinity thereof. The semiconductor laser device shown in Fig. 3 is different from that shown in Fig. 1 in a point that the n-current blocking layer 12A has three layers while the n-current
25 blocking layer 12 has nine layers. The structures of the

remaining parts of the semiconductor laser device shown in Fig. 3 and a method of manufacturing the same are similar to those of the semiconductor laser device shown in Fig. 1.

As shown in the energy band diagram of Fig. 3, the n-current blocking layer 12A formed on a p-first cladding layer 11 of p-BAlGa_N is formed by alternately stacking two n-first current blocking layers 12c of BAlGa_N each having a thickness of 0.25 μm and an n-second current blocking layer 12d of BInGa_N having a thickness of 0.05 μm .

The n-first current blocking layers 12a shown in Fig. 2 and the n-first current blocking layers 12c shown in Fig. 3 as well as the n-second current blocking layers 12b shown in Fig. 2 and the n-second current blocking layer 12d shown in Fig. 3 are identical in composition and growth condition to each other, except the thicknesses.

The compositions, thicknesses and growth conditions of respective layers forming the semiconductor laser device shown in Fig. 3, excluding the n-current blocking layer 12A, are similar to those of the layers 2 to 11, 14 and 15 forming the semiconductor laser device shown in Fig. 1. The energy level of the n-first current blocking layers 12c on the lower end of the conduction band is identical to that of the n-first current blocking layers 12a on the lower end of the conduction band, and the energy level of the n-second current blocking layer 12d on the lower end of the conduction band is identical

to that of the n-second current blocking layers 12b on the lower end of the conduction band. The mean energy level E3 of the n-current blocking layer 12A on the lower end of the conduction band is set higher than that of the p-first cladding layer 11 and the p-second cladding layer 14 on the lower end of the conduction band.

In the semiconductor laser device according to this embodiment having the aforementioned structure, an effect of light confinement by the n-current blocking layer 12A can be improved while the p-first cladding layer 11, the n-current blocking layer 12A and the p-second cladding layer 14 are hardly cracked similarly to the semiconductor laser device according to the first embodiment. Further, thermal stability is improved due to the n-first current blocking layers 12c containing boron and aluminum.

(3) Third Embodiment

Fig. 4 is an energy band diagram of a current blocking layer 12B of a GaN based semiconductor laser device according to a third embodiment of the present invention and the vicinity thereof. The semiconductor laser device shown in Fig. 4 is different from that shown in Fig. 1 in a point that the n-current blocking layer 12B has a different composition different from the n-current blocking layer 12. The structures of the remaining parts of the semiconductor laser device shown in Fig. 4 and a method of manufacturing the same are identical

to those of the semiconductor laser device shown in Fig. 1.

As shown in the energy band diagram of Fig. 4, the n-current blocking layer 12B formed on a first cladding layer 11 of p-BAlGa_N is formed by alternately stacking five first current blocking layers 12e of n-BAlGa_N each having a thickness of 0.1 μm and four n-BInGa_N second current blocking layers 12f each having a thickness of 0.01 μm.

Table 2 shows the compositions, thicknesses and growth temperatures of partial layers related to the semiconductor laser device shown in Fig. 4. The compositions, thicknesses and growth temperatures of the layers, excluding the n-current blocking layer 12B, are similar to those of the layers 2 to 12, 14 and 15 of the semiconductor laser device shown in Fig. 1 (Table 1).

Table 2

Name of Layer	Composition	Thickness	Growth Temperature [°C]
Quantum Barrier Layer	B _{0.02} In _{0.05} Ga _{0.93} N	50 Å	800
Quantum Well Layer	B _{0.02} In _{0.15} Ga _{0.83} N	20 Å	800
p-First Cladding Layer	B _{0.02} Al _{0.05} Ga _{0.93} N	0.2 μm	1080
n-First Current Blocking Layer	B _{0.02} Al _{0.07} Ga _{0.91} N	0.1 μm	1080
n-Second Current Blocking Layer	B _{0.02} In _{0.18} Ga _{0.80} N	0.01 μm	800
p-Second Cladding Layer	B _{0.02} Al _{0.05} Ga _{0.93} N	0.7 μm	1080

As understood from Fig. 4, the band gap of the n-first current blocking layers 12e is larger than that of the p-first cladding layer 11 and a p-second cladding layer 14. On the other hand, the band gap of the n-second current blocking layers 12f is smaller than that of quantum well layers forming an MQW active layer 8. The mean energy level E_4 of the n-first current blocking layers 12e and the n-second current blocking layers 12f on the lower end of the conduction band is set higher than the energy level of the p-first cladding layer 11 and the p-second cladding layer 14 on the lower end of the conduction band.

In the semiconductor laser device according to this embodiment, the n-second current blocking layers 12f of n-BInGaN having a smaller band gap than the n-first current blocking layers 12e of n-BAlGaN are held between the n-first current blocking layers 12e, for increasing an effect of preventing cracking. Particularly as compared with the first embodiment, the composition ratio of indium in the n-BInGaN second current blocking layers 12f is larger than that in the n-BInGaN second current blocking layers 12b, for more effectively preventing cracking.

The thermal stability of the n-current blocking layer 12B is improved due to the n-first current blocking layers 12e containing aluminum and boron. Further, the mean energy level E_4 of the n-first current blocking layers 12e and the n-second

current blocking layers 12f on the lower end of the conduction band is higher than the energy level of the p-first cladding layer 11 and the p-second cladding layer 14 on the lower end of the conduction band, whereby the mean refractive index of the n-current blocking layer 12B is smaller than those of the p-first cladding layer 11 and the p-second cladding layer 14 so that light is concentrated to a region of the MQW active layer 8 located under a striped opening 13 of the n-current blocking layer 12B and an effect of light confinement is improved. As compared with the first embodiment, however, the band gap of the n-second current blocking layers 12f of n-BInGaN is smaller than that of the n-second current blocking layers 12b of n-BInGaN, and hence it is easier to control the mean energy level of the n-current blocking layer 12 on the lower end of the conduction band in the semiconductor laser device according to the first embodiment.

(4) Fourth Embodiment

Fig. 5 is an energy band diagram of a current blocking layer of 12C a GaN based semiconductor laser device according to a fourth embodiment of the present invention and the vicinity thereof.

The semiconductor laser device shown in Fig. 5 is different from that shown in Fig. 4 in a point that the n-current blocking layer 12C has three layers while the n-current blocking layer 12B has nine layers. The structures of the

remaining parts of the semiconductor laser device shown in Fig. 5 and a method of manufacturing the same are identical to those of the semiconductor laser device shown in Fig. 3, i.e., those of the semiconductor laser device shown in Fig. 1.

5 As shown in the energy band diagram of Fig. 5, the n-current blocking layer 12C formed on a p-first cladding layer 11 of p-BAlGa_N is formed by alternately stacking two n-first current blocking layers 12g of BAlGa_N each having a thickness of 0.025 μm and an n-second current blocking layer 12h of BInGa_N 10 having a thickness of 0.05 μm . The n-first current blocking layers 12e shown in Fig. 4 and the n-first current blocking layers 12g shown in Fig. 5 as well as the n-second current blocking layers 12f shown in Fig. 4 and the n-second current blocking layer 12h shown in Fig. 5 are identical in composition 15 and growth condition to each other, except the thicknesses. The compositions, thicknesses and growth temperatures of layers forming the semiconductor laser device shown in Fig. 5, excluding the n-current blocking layer 12C, are similar to those of the layers forming the semiconductor laser device 20 shown in Fig. 4, i.e., those of the layers 2 to 12, 14 and 15 of the semiconductor laser device shown in Fig. 1.

The band gap of the n-first current blocking layers 12g of BAlGa_N is equivalent to that of the n-first current blocking layers 12e of BAlGa_N, and the band gap of the n-second current 25 blocking layer 12h of BInGa_N is equivalent to that of the

n-second current blocking layers 12f of BInGaN. The mean energy level E5 of the n-current blocking layer 12C on the lower end of the conduction band is set higher than the energy level of the p-first cladding layer 11 and a p-second cladding layer 14 on the lower end of the conduction band.

In the semiconductor laser device according to the fourth embodiment having the aforementioned structure, an effect of light confinement by the n-current blocking layer 12C and thermal stability can be improved while the p-first cladding layer 11, the n-current blocking layer 12C and the p-second cladding layer 14 are hardly cracked, similarly to the semiconductor laser device according to the third embodiment.

(5) Fifth Embodiment

Fig. 6 is an energy band diagram of a current blocking layer 12D of a GaN based semiconductor laser device according to a fifth embodiment of the present invention and the vicinity thereof.

The semiconductor laser device shown in Fig. 6 is different from that shown in Fig. 1 in a point that the composition of the n-current blocking layer 12D is different from that of the n-current blocking layer 12. The structures of the remaining parts of the semiconductor laser device shown in Fig. 6, excluding the n-current blocking layer 12D, and a method of manufacturing the same are identical to those of the semiconductor laser device shown in Fig. 1.

As shown in the energy band diagram of Fig. 6, the n-current blocking layer 12D formed on a p-first cladding layer 11 of BaInGaN is prepared by alternately stacking five n-first current blocking layers 12i of BaInGaN each having a thickness of $0.1 \mu\text{m}$ and four n-second current blocking layers 12k of BiInGaN each having a thickness of $0.01 \mu\text{m}$.

Table 3 shows the compositions, thicknesses and growth temperatures of partial layers related to the semiconductor laser device shown in Fig. 6. The compositions, thicknesses and growth temperatures of the layers, excluding the n-current blocking layer 12D, are similar to those of the layers 2 to 12, 14 and 15 of the semiconductor laser device shown in Fig. 1 (Table 1).

Table 3

Name of Layer	Composition	Thickness	Growth Temperature [°C]
Quantum Barrier Layer	$\text{B}_{0.02}\text{In}_{0.05}\text{Ga}_{0.93}\text{N}$	50 Å	800
Quantum Well Layer	$\text{B}_{0.02}\text{In}_{0.15}\text{Ga}_{0.83}\text{N}$	20 Å	800
p-First Cladding Layer	$\text{B}_{0.02}\text{Al}_{0.05}\text{Ga}_{0.93}\text{N}$	$0.2 \mu\text{m}$	1080
n-First Current Blocking Layer	$\text{B}_{0.02}\text{Al}_{0.02}\text{In}_{0.08}\text{Ga}_{0.88}\text{N}$	$0.1 \mu\text{m}$	800
n-Second Current Blocking Layer	$\text{B}_{0.02}\text{In}_{0.18}\text{Ga}_{0.80}\text{N}$ $-\text{B}_{0.02}\text{In}_{0.20}\text{Ga}_{0.78}\text{N}$	$0.01 \mu\text{m}$	800
p-Second Cladding Layer	$\text{B}_{0.02}\text{Al}_{0.05}\text{Ga}_{0.93}\text{N}$	$0.7 \mu\text{m}$	1080

As shown in Fig. 6, the band gap of the n-second current blocking layers 12k of BInGaN is smaller than that of quantum well layers forming an MQW active layer 8. The band gap of the n-first current blocking layers 12i of BAInGaN is substantially identical to or smaller than that of quantum barrier layers forming the MQW active layer 8. Therefore, the mean energy level E6 of the n-current blocking layer 12D on the lower end of the conduction band is set substantially identical to or not more than the mean energy level E1 of the MQW active layer 8 on the lower end of the conduction band.

In the semiconductor laser device according to this embodiment, the total thickness of the layers prepared by adding at least one of Al and B to GaN is $0.9\ \mu\text{m}$, while the n-second current blocking layers 12k of BInGaN having a smaller band gap than the n-first current blocking layers 12i of BAInGaN are held between the n-first current blocking layers 12i of BAInGaN, whereby cracking can be prevented while improving thermal stability of the n-current blocking layer 12D.

In this case, the mean energy level E6 of the n-current blocking layer 12D formed by the five n-first current blocking layers 12i and the four n-second current blocking layers 12k on the lower end of the conduction band is set lower than the mean energy level E1 of the MQW active layer 8 on the lower end of the conduction band, whereby the n-current blocking

layer 12D absorbs light generated in the region of the active layer 8 located under the n-current blocking layer 12D so that light is concentrated to the region of the active layer 8 located under a striped opening 13 of the n-current blocking layer 12D.

5 Thus, a semiconductor laser device having a loss guided structure is obtained.

The mean energy level E6 of the n-current blocking layer 12D on the lower end of the conduction band can be controlled smaller than the mean energy level E1 of the active layer 8 on the lower end of the conduction band by employing a material
10 having a smaller band gap than that of the quantum well layers forming the MQW active layer 8 for the n-second current blocking layers 12k.

(6) Sixth Embodiment

15 Fig. 7 is an energy band diagram of a current blocking layer of a GaN based semiconductor laser device according to a sixth embodiment of the present invention and the vicinity thereof. The semiconductor laser device shown in Fig. 7 is different from that shown in Fig. 6 in a point that an n-current
20 blocking layer 12E has a three stacked layers while the n-current blocking layer 12D has nine stacked layers. The structures of the remaining parts of the semiconductor laser device shown in Fig. 7 and a method of manufacturing the same are identical to those of the semiconductor laser device shown
25 in Fig. 6, i.e., those of the semiconductor laser device shown

in Fig. 1.

As shown in Fig. 7, the n-current blocking layer 12E formed on a p-first cladding layer 11 of p-BAlGa_N is prepared by alternately stacking two n-first current blocking layers 12m of BAlInGa_N each having a thickness of 0.25 μm and an n-second current blocking layer 12n of BInGa_N having a thickness of 0.05 μm . The n-first current blocking layers 12m shown in Fig. 7 and the n-first current blocking layers 12i shown in Fig. 6 as well as the n-second current blocking layer 12n shown in Fig. 7 and the n-second current blocking layers 12k shown in Fig. 6 are identical in composition and growth temperature to each other, except the thicknesses. The compositions, thicknesses and growth temperatures of layers forming the semiconductor laser device shown in Fig. 7, excluding the n-current blocking layer 12E, are similar to those of the layers forming the semiconductor laser device shown in Fig. 6, i.e., those of the layers 2 to 12, 14 and 15 of the semiconductor laser device shown in Fig. 1.

The band gap of the n-first current blocking layers 12m of BAlInGa_N is equivalent to that of the n-first current blocking layers 12i of BAlInGa_N, and the band gap of the n-second current blocking layer 12n of BInGa_N is equivalent to that of the n-second current blocking layers 12k of BInGa_N. The mean energy level E7 of the n-current blocking layer 12E on the lower end of the conduction band is set substantially identical to

or lower than the mean energy level E1 of an MQW active layer 8 on the lower end of the conduction band.

In the semiconductor laser device according to this embodiment having the aforementioned structure, the thermal stability of the n-current blocking layer 12E can be improved by increasing the composition ratio of at least either aluminum or boron, similarly to the semiconductor laser device according to the fifth embodiment. At the same time, the n-second current blocking layer 12n of BiN_{0.5}Ga_{0.5}N is held between the n-first current blocking layers 12m, whereby the p-first cladding layer 11, the n-current blocking layer 12E and a p-second cladding layer 14 are hardly cracked.

(7) Seventh Embodiment

Fig. 8 is a typical sectional view of a GaN based semiconductor laser device according to a seventh embodiment of the present invention.

As shown in Fig. 8, a buffer layer 2, an n-BGaN layer 4, an n-anti-cracking layer 5, an n-cladding layer 6, an n-light guide layer 7, an n-MQW active layer 8, a p-carrier blocking layer 9, a p-light guide layer 10 and a p-first cladding layer 11 are successively formed on a conductive substrate 18 such as a GaN substrate. An n-current blocking layer 12 having a striped opening 13 is formed on the p-first cladding layer 11. A p-second cladding layer 14 is formed on the p-first cladding layer 11 located in the striped opening 13 and the n-current

blocking layer 12. A p-contact layer 15 is formed on the p-second cladding layer 14. A p type electrode 16 is formed on the p-contact layer 15, and an n type electrode 17 is formed on the back surface of the conductive substrate 18. The semiconductor laser device shown in Fig. 8 is provided with no B_{0.2}GaN layer 3, dissimilarly to the semiconductor laser device shown in Fig. 1. Also in the semiconductor laser device shown in Fig. 8, the n-current blocking layer 12 is formed by alternately stacking five n-first current blocking layers 12a of B_{0.2}AlGaN each having a thickness of 0.1 μm and four n-second current blocking layers 12b of B_{0.2}InGaN each having a thickness of 0.02 μm as shown in the energy band diagram of Fig. 2, similarly to the semiconductor laser device shown in Fig. 1.

The compositions, thicknesses and growth conditions of the layers 2, 4 to 12, 14 and 15 forming the semiconductor laser device shown in Fig. 8 are similar to those of the layers 2, 4 to 12, 14 and 15 forming the semiconductor laser device shown in Fig. 1.

In the semiconductor laser device according to this embodiment, the n-second current blocking layers 12b of B_{0.2}InGaN having a smaller band gap than the n-first current blocking layers 12a of B_{0.2}AlGaN are held between the n-first current blocking layers 12a for effectively absorbing strain caused in the n-first current blocking layers 12a arranged on both sides thereof, thereby preventing cracking. In particular,

the n-second current blocking layers 12b containing indium attain a large anti-cracking effect.

The refractive index of the n-current blocking layer 12 is smaller than those of the p-first cladding layer 11 and the p-second cladding layer 14 so that the effective refractive index in the region of the MQW active layer 8 located under the striped opening 13 is smaller than the refractive index in the region of the MQW active layer 8 located under the n-current blocking layer 12 for increasing an effect of concentrating light to the region located under the striped opening 13.

Further, it is possible to readily control the mean energy level E2 of the n-current blocking layer 12 on the lower end of the conduction band higher than the energy level of the p-first cladding layer 11 and the p-second cladding layer 14 on the lower end of the conduction band by increasing the thickness of the n-first current blocking layers 12a beyond that of the n-second current blocking layers 12b.

(8) Eighth Embodiment

A GaN based semiconductor laser device according to an eighth embodiment of the present invention is now described.

The semiconductor laser device according to this embodiment is similar in structure to the semiconductor laser device shown in Fig. 1 except the materials for respective layers. Table 4 shows the compositions, thicknesses and growth

temperatures of the layers forming the semiconductor laser device according to this embodiment.

Table 4

Name of Layer	Composition	Thickness	Growth Temperature [°C]
Low-Temperature Buffer Layer	$\text{Al}_{0.5}\text{Ga}_{0.5}\text{N}$	200 Å	600
i-GaN Layer	GaN	$4.5\text{ }\mu\text{m}$	1080
n-GaN Layer	GaN	$4.5\text{ }\mu\text{m}$	1080
Anti-Cracking Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N/GaN}$	$0.25\text{ }\mu\text{m}$	1080
n-Cladding Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$	$0.8\text{ }\mu\text{m}$	1080
n-Light Guide Layer	GaN	$0.1\text{ }\mu\text{m}$	1080
Quantum Barrier Layer	$\text{In}_{0.02}\text{Ga}_{0.98}\text{N}$	50 Å	800
Quantum Well Layer	$\text{In}_{0.10}\text{Ga}_{0.90}\text{N}$	20 Å	800
p-Carrier Blocking Layer	$\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$	200 Å	800
p-Light Guide Layer	GaN	$0.1\text{ }\mu\text{m}$	1080
p-First Cladding Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$	$0.2\text{ }\mu\text{m}$	1080
n-First Current Blocking Layer	$\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$	$0.1\text{ }\mu\text{m}$	1080
n-Second Current Blocking Layer	$\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$	$0.02\text{ }\mu\text{m}$	800
p-Second Cladding Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$	$0.7\text{ }\mu\text{m}$	1080
p-Contact Layer	GaN	$0.05\text{ }\mu\text{m}$	1080

As shown in Table 4, a low-temperature buffer layer 2 is made of AlGaN, an undoped GaN layer is provided in place

of the BGaN layer 3, and an n-GaN layer is provided in place of the n-BGaN layer 4. An n-anti-cracking layer 5 is formed by alternately stacking 21 pairs of AlGaN layers of 60 Å in thickness and GaN layers of 60 Å in thickness, an n-cladding layer 6 is made of AlGaN, and an n-light guide layer 7 is made of GaN.

An n-MQW active layer 8 is formed by alternately stacking four InGaN quantum barrier layers of 50 Å in thickness and three InGaN quantum well layers of 20 Å in thickness. Further, a p-carrier blocking layer 9 is made of AlGaN, a p-light guide layer 10 is made of GaN, a p-first cladding layer 11 and a p-second cladding layer 14 are made of AlGaN, and a p-contact layer 13 is made of GaN. An n-current blocking layer 12 is formed by alternately stacking five n-first current blocking layers 12a of 0.1 μm in thickness and four n-second current blocking layers 12b of 0.02 μm in thickness as shown in the energy band diagram of Fig. 2, while the n-first current blocking layers 12a are made of AlGaN and the n-second current blocking layers 12b are made of InGaN.

TMG, TMA and NH₃ are employed as raw material gases for growing the low-temperature buffer layer 2. TMG and NH₃ are employed as raw material gases for growing the GaN layer. TMG and NH₃ are employed as raw material gases and SiH₄ is employed as a dopant gas for growing the n-GaN layer and the n-light guide layer 7. TMG, TMA and NH₃ are employed as raw material

gases and SiH_4 is employed as a dopant gas for growing the n-anti-cracking layer 5, the n-cladding layer 6 and the n-first current blocking layers 12a.

TEG, TMI and NH_3 are employed as raw material gases and
 5 SiH_4 is employed as a dopant gas for growing the n-MQW active layer 8 and the n-second current blocking layers 12b. TMG, TMA and NH_3 are employed as raw material gases and Cp_2Mg is employed as a dopant gas for growing the p-carrier blocking layer 9, the p-first cladding layer 11 and the p-second cladding
 10 layer 14. TMG and NH_3 are employed as raw material gases and Cp_2Mg is employed as a dopant gas for growing the p-light guide layer 10 and the p-contact layer 15.

The semiconductor laser device according to this embodiment can attain an effect similar to that of the
 15 semiconductor laser device shown in Fig. 1.

(9) Ninth Embodiment

A GaN based semiconductor laser device according to a ninth embodiment of the present invention is now described.

The semiconductor laser device according to this
 20 embodiment is similar in structure to the semiconductor laser device according to the sixth embodiment except the material and the thickness of an n-current blocking layer 12B. Table 5 shows the compositions, thicknesses and growth temperatures of layers forming the semiconductor laser device according to
 25 this embodiment.

Table 5

Name of Layer	Composition	Thickness	Growth Temperature [°C]
Quantum Barrier Layer	$\text{In}_{0.02}\text{Ga}_{0.98}\text{N}$	50 Å	800
Quantum Well Layer	$\text{In}_{0.10}\text{Ga}_{0.90}\text{N}$	20 Å	800
p-First Cladding Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$	0.2 μm	1080
n-First Current Blocking Layer	$\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$	0.1 μm	1080
n-Second Current Blocking Layer	$\text{In}_{0.13}\text{Ga}_{0.87}\text{N}$	0.01 μm	800
p-Second Cladding Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$	0.7 μm	1080

The compositions, thicknesses and growth temperatures of the quantum barrier layers, the quantum well layers, the p-first cladding layer 11 and the p-second cladding layer 14 shown in Table 5 are similar to those of the layers forming the semiconductor laser device shown in Table 4.

As shown in the energy band diagram of Fig. 4, the n-current blocking layer 12B of the semiconductor laser device according to this embodiment is formed by stacking five n-first current blocking layers 12e of AlGa_N each having a thickness of 0.1 μm and four n-second current blocking layers 12f of BInGa_N each having a thickness of 0.01 μm .

The semiconductor laser device according to this embodiment can attain an effect similar to that of the semiconductor laser device shown in Fig. 4.

(10) Tenth Embodiment

A GaN based semiconductor laser device according to a tenth embodiment of the present invention is now described.

The semiconductor laser device according to this embodiment is similar in structure to the semiconductor laser device according to the eighth embodiment except the material and the thickness of an n-current blocking layer 12D. Table 6 shows the compositions, thicknesses and growth temperatures of layers forming the semiconductor laser device according to this embodiment.

Table 6

Name of Layer	Composition	Thickness	Growth Temperature [°C]
Quantum Barrier Layer	$\text{In}_{0.02}\text{Ga}_{0.98}\text{N}$	50 Å	800
Quantum Well Layer	$\text{In}_{0.10}\text{Ga}_{0.90}\text{N}$	20 Å	800
p-First Cladding Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$	0.2 μm	1080
n-First Current Blocking Layer	$\text{Al}_{0.04}\text{In}_{0.08}\text{Ga}_{0.88}\text{N}$	0.1 μm	800
n-Second Current Blocking Layer	$\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$	0.01 μm	800
p-Second Cladding Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$	0.7 μm	1080

The compositions, thicknesses and growth temperatures of the quantum barrier layers, the quantum well layers, the p-first cladding layer 11 and the p-second cladding layer 14 shown in Table 6 are similar to those of the layers forming the semiconductor laser device shown in Table 4.

As shown in the energy band diagram of Fig. 6, the

n-current blocking layer 12D of the semiconductor laser device according to this embodiment is formed by alternately stacking five n-first current blocking layers 12i of AlInGaN each having a thickness of $0.1\text{ }\mu\text{m}$ and four n-second current blocking layers 12k of InGaN each having a thickness of $0.01\text{ }\mu\text{m}$.

The semiconductor laser device according to this embodiment can attain an effect similar to that of the semiconductor laser device shown in Fig. 6.

(11) Eleventh Embodiment

Fig. 9 is a typical sectional view of a GaN based semiconductor laser device according to an eleventh embodiment of the present invention. Fig. 10 is an energy band diagram of an n-current blocking layer 42 of the semiconductor laser device shown in Fig. 9 and the vicinity thereof. The semiconductor laser device shown in Fig. 9 has a striped ridge part 41a in a p-cladding layer 41.

Layers from a sapphire substrate 1 to a p-light guide layer 10 forming the semiconductor laser device according to this embodiment are similar in structure to the layers forming the semiconductor laser device shown in Fig. 1. The n-current blocking layer 42 of the semiconductor laser device according to this embodiment is similar to the n-current blocking layer 12 shown in Fig. 1, except the sectional shape of a striped opening 45 in a direction perpendicular to the longitudinal direction thereof. Table 7 shows the compositions,

thicknesses and growth temperatures of the layers formed on the p-light guide layers 10 of the semiconductor laser device according to this embodiment.

Table 7

Name of Layer	Composition	Thickness	Growth Temperature [°C]
p-Cladding Layer	$B_{0.02}Al_{0.05}Ga_{0.93}N$	$0.2 \mu m$	1080
n-First Current Blocking Layer	$B_{0.02}Al_{0.07}Ga_{0.91}N$	$0.1 \mu m$	1080
n-Second Current Blocking Layer	$B_{0.02}In_{0.08}Ga_{0.90}N$	$0.02 \mu m$	800
p-Cap Layer	$B_{0.02}Ga_{0.98}N$	$0.1 \mu m$	1080
p-Contact Layer	$B_{0.02}Ga_{0.98}N$	$0.05 \mu m$	1080

- 5 As shown in Table 7, the p-cladding layer 41 of $BAlGaN$ having the ridge part 41a is provided on the p-light guide layer 10 of $BGaN$. The thickness of the p-cladding layer 41 excluding the region of the ridge part 41a is $0.2 \mu m$. A p-cap layer 43 of $BGaN$ is formed on the ridge part 41a of the p-cladding layer 10 41, and the n-current blocking layer 42 is provided on portions of the p-cladding layer 41 located on both sides of the ridge part 41a. A p-contact layer 44 of $BGaN$ is provided on the n-current blocking layer 42 and the p-cap layer 43. In the p-cladding layer 41, the ridge part 41a corresponds to a 15 p-second cladding layer, and the remaining part corresponds to a p-first cladding layer.

Similarly to the semiconductor laser device shown in Fig.

1, the n-current blocking layer 42 is formed by alternately stacking five n-first current blocking layers 42a of BaInGaN each having a thickness of $0.1 \mu\text{m}$ and four n-second current blocking layers 42b of BiInGaN each having a thickness of $0.02 \mu\text{m}$, as shown in Fig. 10.

TMG, TMA, NH_3 and B_2H_4 are employed as raw material gases and Cp_2Mg is employed as a dopant gas for growing the p-BaInGaN cladding layer 41. TMG, NH_3 and B_2H_4 are employed as raw material gases and Cp_2Mg is employed as a dopant gas for growing the p-BGaN cap layer 43 and the p-BGaN contact layer 44. TMG, TMA, NH_3 and B_2H_4 are employed as raw material gases and SiH_4 is employed as a dopant gas for growing the n-first current blocking layers 42a. TEG, TMI, NH_3 and B_2H_4 are employed as raw material gases and SiH_4 is employed as a dopant gas for growing the n-second current blocking layers 42b.

The semiconductor laser device according to this embodiment can attain an effect similar to that of the semiconductor laser device shown in Fig. 1.

While the five n-first current blocking layers 42a and the four n-second current blocking layers 42b are alternately stacked in the eleventh embodiment, the numbers of the stacked n-first current blocking layers and n-second current blocking layers are not restricted to the above. At least two n-first current blocking layers and at least one second current blocking layer may be alternately stacked. Thus, the n-first

current blocking layers hold the n-second current blocking layer(s) therebetween, so that the n-second current blocking layer(s) can effectively absorb strain of the n-first current blocking layers caused on both sides thereof.

5 While the band gap of the n-second current blocking layers 42b of BInGaN is larger than the band gap of quantum well layers forming an MQW active layer 8 in the eleventh embodiment, the band gap of the n-second current blocking layers may be rendered smaller than that of the quantum well layers by increasing the
10 composition ratio of indium so that the composition of the n-second current blocking layers is $B_{0.02}In_{0.15}Ga_{0.83}N$, for example.

While the mean refractive index of the n-current blocking layer 42 is set smaller than the refractive index of the
15 p-cladding layer 41 of BAlGaIn to provide a real refractive index guided structure in the aforementioned eleventh embodiment, the mean band gap of the n-current blocking layer may be rendered smaller than that of the MQW active layer 8, for obtaining a semiconductor laser device having a loss guided structure
20 similarly to the semiconductor laser device shown in Fig. 6 in this case.

(12) Twelfth Embodiment

A semiconductor laser device according to a twelfth embodiment of the present invention is now described.

25 A typical sectional structure of the semiconductor laser

device according to this embodiment is similar to that of the semiconductor laser device according to the eleventh embodiment shown in Fig. 9. However, the materials for layers forming the semiconductor laser device according to this embodiment are different from those forming the layers of the semiconductor laser device according to the eleventh embodiment. The respective layers from a sapphire substrate 1 to a p-light guide layer 10 forming the semiconductor laser device according to this embodiment are identical to the layers forming the semiconductor layer according to the eighth embodiment shown in Table 4. Table 8 shows the compositions, thicknesses and growth temperatures of layers formed on the p-light guide layer 10 of the semiconductor laser device according to this embodiment.

Table 8

Name of Layer	Composition	Thickness	Growth Temperature [°C]
p-Cladding Layer	$\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$	$0.2\ \mu\text{m}$	1080
n-First Current Blocking Layer	$\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$	$0.1\ \mu\text{m}$	1080
n-Second Current Blocking Layer	$\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$	$0.02\ \mu\text{m}$	800
p-Cap Layer	GaN	$0.1\ \mu\text{m}$	1080
p-Contact Layer	GaN	$0.05\ \mu\text{m}$	1080

A p-cladding layer 41 formed on the p-GaN light guide layer 10 is made of AlGa_N and has a thickness of $0.2\ \mu\text{m}$ except

the region of a ridge part 41a. A p-cap layer 43 is made of GaN and has a thickness of $0.1\ \mu\text{m}$. An n-current blocking layer 42 is formed by alternately stacking five n-first current blocking layers 42a of AlGaIn each having a thickness of $0.1\ \mu\text{m}$ and four n-second current blocking layers 42b of InGaIn each having a thickness of $0.02\ \mu\text{m}$, as shown in Fig. 10. A contact layer 44 of GaN having a thickness of $0.05\ \mu\text{m}$ is formed on the n-current blocking layer 42 and the p-cap layer 43.

TMG, TMA, NH_3 and B_2H_6 are employed as raw material gases and Cp_2Mg is employed as a dopant gas for growing the p-cladding layer 41. TMG, NH_3 and B_2H_6 are employed as raw material gases and Cp_2Mg is employed as a dopant gas for growing the p-cap layer 43 and the p-contact layer 44. TMG, TMA and NH_3 are employed as raw material gases and SiH_4 is employed as a dopant gas for growing the n-first current blocking layers 42a. TEG, TMI and NH_3 are employed as raw material gases and SiH_4 is employed as a dopant gas for growing the n-second current blocking layers 42b.

The semiconductor laser device according to this embodiment can attain an effect similar to that of the semiconductor laser device according to the eighth embodiment.

While the five n-first current blocking layers 42a and the four n-second current blocking layers 42b are alternately stacked in the twelfth embodiment, the numbers of the stacked n-first current blocking layers and n-second current blocking

layers are not restricted to the above. At least two n-first current blocking layers and at least one second current blocking layer may be alternately stacked. Thus, the n-first current blocking layers hold the n-second current blocking layer(s) therebetween, so that the n-second current blocking layer(s) can effectively absorb strain of the n-first current blocking layers caused on both sides thereof.

While the band gap of the n-second current blocking layers 42b of InGaN is larger than the band gap of quantum well layers forming an MQW active layer 8 in the twelfth embodiment, the band gap of the n-second current blocking layers may be rendered smaller than that of the quantum well layers by increasing the composition ratio of indium so that the composition of the second current blocking layers is $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$, for example.

While the mean refractive index of the n-current blocking layer 42 is set smaller than the refractive index of the p-cladding layer 41 of AlGaIn to provide a real refractive index guided structure in the aforementioned twelfth embodiment, the mean band gap of the n-current blocking layer may be rendered smaller than that of the MQW active layer 8, for obtaining a semiconductor laser device having a loss guided structure similarly to the semiconductor laser device according to the tenth embodiment in this case.

(13) Thirteenth Embodiment

Fig. 11 is a typical sectional view of a GaN based

semiconductor laser device according to a thirteenth embodiment of the present invention.

As shown in Fig. 11, a buffer layer 2, an n-BGaN layer 4, an n-anti-cracking layer 5, an n-cladding layer 6, an n-light guide layer 7, an n-MQW active layer 8, a p-carrier blocking layer 9, a p-light guide layer 10 and a p-cladding layer 41 are successively formed on a conductive substrate 18 such as a GaN substrate. A striped ridge part 41a is formed in the p-cladding layer 41. An n-current blocking layer 42 is formed on parts of the p-cladding layer 41 located on both sides of the striped ridge part 41a. A p-cap layer 43 is formed on the striped ridge part 41a. A p-contact layer 44 is formed on the n-current blocking layer 42 and the p-cap layer 43. A p type electrode 16 is formed on the p-contact layer 44, and an n type electrode 17 is formed on the back surface of the conductive substrate 18. The semiconductor laser device shown in Fig. 11 is provided with no BGaN layer 3, dissimilarly to the semiconductor laser device shown in Fig. 9.

The compositions, thicknesses and growth conditions of the layers 2, 4 to 10 and 41 to 44 forming the semiconductor laser device shown in Fig. 11 are similar to those of the layers 2, 4 to 10 and 41 to 44 forming the semiconductor laser device shown in Fig. 9. Also in the semiconductor laser device shown in Fig. 11, the n-current blocking layer 42 is formed by alternately stacking five n-first current blocking layers 42a

of $0.1\ \mu\text{m}$ in thickness and four n-second current blocking layers 42b of $0.02\ \mu\text{m}$ in thickness as shown in the energy band diagram of Fig. 10, similarly to the semiconductor laser device shown in Fig. 9. The first current blocking layers 42a are made of AlGaIn, and the n-second current blocking layers 42b are made of InGaIn.

In the semiconductor laser device according to this embodiment, the n-second current blocking layers 42b of InGaIn having a smaller band gap than the n-first current blocking layers 42a of AlGaIn are held between the n-first current blocking layers 42a to effectively absorb strain caused in the n-first current blocking layers 42a located on both sides thereof, so that cracking is hardly caused. In particular, the n-second current blocking layers 42b contain indium, to attain a large anti-cracking effect.

The refractive index of the n-current blocking layer 42 is smaller than that of the p-cladding layer 14 so that the effective refractive index in the region of the MQW active layer 8 located under a striped opening 45 is smaller than the effective refractive index of the MQW active layer 8 located under the n-current blocking layer 42 for increasing an effect of concentrating light to the region located under the striped opening 45. Thus, a semiconductor laser device of a real refractive index guided structure is implemented.

Further, it is possible to readily control the mean energy

level E8 of the n-current blocking layer 42 on the lower end of the conduction band higher than the energy level of the p-cladding layer 41 on the lower end of the conduction band by increasing the thickness of the n-first current blocking layers 42a beyond that of the n-second current blocking layers 42b.

While the five n-first current blocking layers 42a and the four n-second current blocking layers 42b are alternately stacked in the thirteenth embodiment, the numbers of the stacked n-first current blocking layers and n-second current blocking layers are not restricted to the above. At least two n-first current blocking layers and at least one second current blocking layer may be alternately stacked. Thus, the n-first current blocking layers hold the n-second current blocking layer(s) therebetween, so that the n-second current blocking layer(s) can effectively absorb strain of the n-first current blocking layers caused on both sides thereof.

While the band gap of the n-second current blocking layers 42b is larger than the band gap of quantum well layers forming the MQW active layer 8 in the thirteenth embodiment, the band gap of the n-second current blocking layers may be rendered smaller than that of the quantum well layers by increasing the composition ratio of indium so that the composition of the n-second current blocking layers is $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$, for example.

While the mean refractive index of the n-current blocking

layer 42 is set smaller than the refractive index of the p-cladding layer 41 of AlGaIn to provide a real refractive index guided structure in the aforementioned thirteenth embodiment, the mean band gap of the n-current blocking layer may be rendered
5 smaller than the band gap of the MQW active layer 8, for obtaining a semiconductor laser device having a loss guided structure similarly to the semiconductor laser device according to the tenth embodiment in this case.

The compositions and thicknesses of the n-first current
10 blocking layers 12a, 12c, 12e, 12g, 12i and 42a, which are first layers, and the n-second current blocking layers 12b, 12d, 12f, 12h, 12k and 42b, which are second layers, are not restricted to those of the aforementioned embodiments, so far as the first layers are made of a nitride based semiconductor containing
15 at least one of aluminum and boron, the second layers are made of a nitride based semiconductor containing indium and the band gap of the second layers is smaller than that of the first layers.

The compositions of the p-first cladding layers 11 and
20 41 and the p-second cladding layers 14 and 41a may be different from each other.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be
25 taken by way of limitation, the spirit and scope of the present

invention being limited only by the terms of the appended claims.

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WHAT IS CLAIMED IS:

1. A semiconductor laser device comprising:

a first nitride based semiconductor layer including an
5 active layer and containing at least one of boron, aluminum,
gallium, indium and thallium;

a current blocking layer, formed on said first nitride
based semiconductor layer, having a striped opening; and

a second nitride based semiconductor layer, formed on
10 said first nitride based semiconductor layer in said striped
opening, containing at least one of boron, aluminum, gallium,
indium and thallium, wherein

said current blocking layer includes a multilayer
structure of at least one first layer of a nitride based
15 semiconductor containing at least one of aluminum and boron
and at least one second layer of a nitride based semiconductor
containing indium and having a smaller band gap than said first
layer.

20 2. The semiconductor laser device according to claim 1,
wherein

said at least one first layer has a larger aluminum
composition ratio than that of said at least one second layer
or a larger boron composition ratio than that of said at least
25 one second layer, and

said at least one second layer has a larger indium composition ratio than that of said at least one first layer.

3. The semiconductor laser device according to claim 1,
5 wherein

said first nitride based semiconductor layer includes a first conductivity type cladding layer, said active layer and a second conductivity type first cladding layer in this order, and

10 said second nitride based semiconductor layer includes a second conductivity type second cladding layer.

4. The semiconductor laser device according to claim 1,
wherein

15 said at least one first layer includes at least two first layers, and said at least two first layers and said at least one second layer are alternately stacked.

5. The semiconductor laser device according to claim 1,
20 wherein

the mean refractive index of said current blocking layer is smaller than the refractive index of said second nitride based semiconductor layer in said striped opening.

25 6. The semiconductor laser device according to claim 5,

wherein

the thickness of each of said at least one first layer is larger than the thickness of each of said at least one second layer.

5

7. The semiconductor laser device according to claim 3, wherein

the mean band gap of said current blocking layer is larger than the band gap of said second conductivity type second cladding layer.

10

8. The semiconductor laser device according to claim 7, wherein

said active layer includes at least one quantum well layer and at least two quantum barrier layers alternately stacked, and

15

the band gap of said at least one second layer is larger than the band gap of said at least one quantum well layer.

20

9. The semiconductor laser device according to claim 3, wherein

said active layer contains indium, gallium and nitrogen, said at least one first layer contains at least one of aluminum and boron as well as gallium and nitrogen,

25

said at least one second layer contains indium, gallium

and nitrogen, and

said first conductivity type cladding layer, said second conductivity type first cladding layer and said second conductivity type second cladding layer contain aluminum, gallium and nitrogen.

10. The semiconductor laser device according to claim 9, wherein

said at least one first layer has a larger aluminum composition ratio than that of said second conductivity type second cladding layer or a larger boron composition ratio than that of said second conductivity type second cladding layer.

11. The semiconductor laser device according to claim 9, wherein

said active layer includes at least one quantum well layer containing indium, gallium and nitrogen and at least two quantum barrier layers containing indium, gallium and nitrogen, alternately stacked, and the indium composition ratio of said at least one quantum well layer is larger than the indium composition ratio of said at least two quantum barrier layers.

12. The semiconductor laser device according to claim 1, wherein

the mean band gap of said current blocking layer is

substantially equal to or smaller than the band gap of said active layer.

13. The semiconductor laser device according to claim
5 12, wherein

said active layer includes at least one quantum well layer
and at least two quantum barrier layers alternately stacked,
and

the mean band gap of said current blocking layer is
10 substantially equal to or smaller than the mean band gap of
said active layer.

14. The semiconductor laser device according to claim
13, wherein

15 the band gap of said at least one second layer is smaller
than the band gap of said at least one quantum well layer.

15. The semiconductor laser device according to claim
14, wherein

20 said active layer contains indium, gallium and nitrogen,
said at least one first layer contains at least one of
aluminum and boron as well as indium, gallium and nitrogen,
said at least one second layer contains indium, gallium
and nitrogen, and

25 said first conductivity type cladding layer, said second

conductivity type first cladding layer and said second conductivity type second cladding layer contain aluminum, gallium and nitrogen.

5 16. The semiconductor laser device according to claim 15, wherein

 said active layer includes at least one quantum well layer containing indium, gallium and nitrogen and at least two quantum barrier layers containing indium, gallium and nitrogen,
10 alternately stacked, and the indium composition ratio of said at least one quantum well layer is larger than the indium composition ratio of said at least two quantum barrier layers.

 17. The semiconductor laser device according to claim
15 3, wherein

 said first nitride based semiconductor layer further includes a first conductivity type light guide layer provided between said first conductivity type cladding layer and said active layer and a second conductivity type light guide layer
20 provided between said active layer and said second conductivity type first cladding layer.

 18. The semiconductor laser device according to claim 3, further comprising:

25 a third nitride based semiconductor layer, formed on said

current blocking layer and said second nitride based semiconductor layer, containing at least one of boron, aluminum, gallium, indium and thallium.

5 19. The semiconductor laser device according to claim 18, wherein

 said third nitride based semiconductor layer includes a third cladding layer of said second conductivity type and a second conductivity type contact layer.

10

 20. The semiconductor laser device according to claim 18, wherein

 said third nitride based semiconductor layer includes a second conductivity type contact layer.

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ABSTRACT OF THE DISCLOSURE

An n-current blocking layer is formed by alternately stacking an n-first current blocking layer of a nitride based semiconductor containing Al or B and an n-second current
5 blocking layer of a nitride based semiconductor containing In. In a semiconductor laser device having a real refractive index guided structure, the mean refractive index of the n-current block layer is smaller than the refractive indices of a p-first cladding layer and a p-second cladding layer. In a
10 semiconductor laser device having a loss guided structure, the mean band gap of the n-current blocking layer is substantially equal to or smaller than the mean band gap of an active layer.

FIG. 1

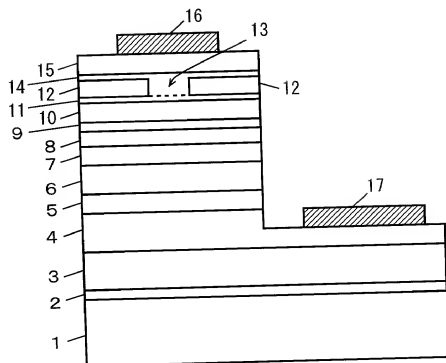


FIG. 2

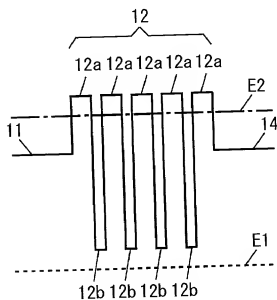


FIG. 3

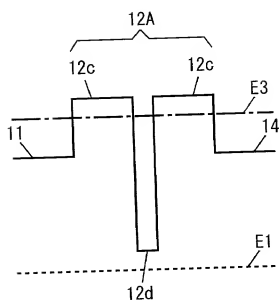


FIG. 4

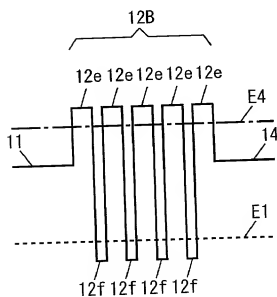


FIG. 5

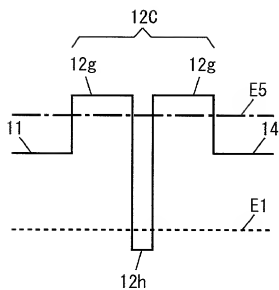
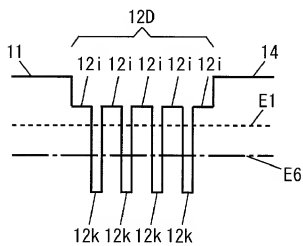
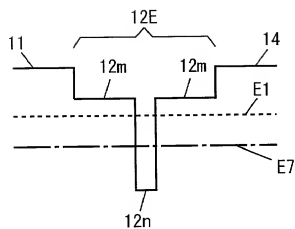


FIG. 6



F I G. 7



F I G. 8

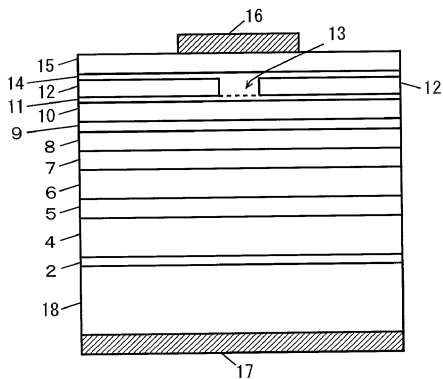


FIG. 9

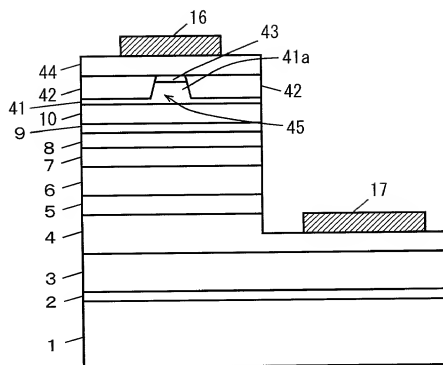


FIG. 10

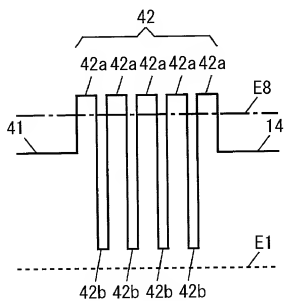


FIG. 11

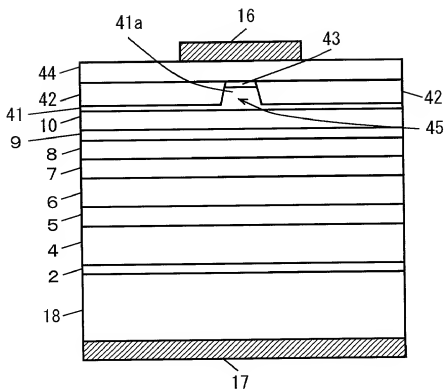
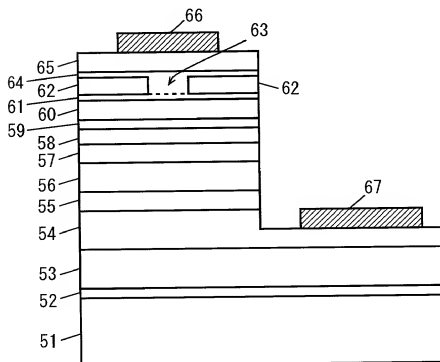


FIG. 12 PRIOR ART



107005

A, W, H, McL & N Docket No. _____

ARMSTRONG, WESTERMAN, HATTORI, McLELAND & NAUGHTON

DECLARATION FOR U.S. PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention **entitled**

(Insert Title) SEMICONDUCTOR LASER DEVICE

the specification of which is attached hereto unless the following is checked:

☐ was filed on _____ as United States Application Number or PCT International Application Number _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claim(s), as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a) - (d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

				Priority Claimed
(List prior foreign applications. See note A on back of this page)	<u>11-079471</u> (Number)	<u>Japan</u> (Country)	<u>24/3/1999</u> (Day/Month/Year Filed)	<u>X</u> Yes ___ No
	<u> </u> (Number)	<u> </u> (Country)	<u> </u> (Day/Month/Year Filed)	___ Yes ___ No
	<u> </u> (Number)	<u> </u> (Country)	<u> </u> (Day/Month/Year Filed)	___ Yes ___ No

(See note B on back of this page) ___ See attached list for additional prior foreign applications

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

<u> </u> (Application Number)	<u> </u> (Filing Date)
<u> </u> (Application Number)	<u> </u> (Filing Date)

005532775 033200

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of the application:

(List Prior U.S. Applications)	(Appln. Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
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(Appln. Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
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I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Title 18 of the United States Code, § 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Citizenship	<u>Japanese</u>	
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